A COMPARATIVE ANALYSIS OF VISUAL LAYOUT TECHNIQUES AS APPLIED TO MEDIUM SIZE JOB MACHINE SHOPS

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ABSTRACT

Visual layout techniques have generally been limited in application to large scale or mass production types of enterprises while smaller enterprises have seldom used such techniques. The purpose of this thesis is to determine which of the several techniques of scientific layout would best satisfy the requirements of a typical job shop layout or re-layout.

Specifically, a medium size job machine shop was selected as the area of study since this type enterprise well represents the smaller metal working trades. After defining the medium size job shop, a typical shop was selected in accordance with the definition. With assumed conditions of space, personnel, equipment, and facilities, the shop was arranged by each of four methods--drafting, templets, models, and templets and models. The final layout obtained by the first technique was duplicated using each of the other methods in turn to provide a basis of comparison of the techniques. A detailed record of procedure during the initial layout provided a standard sequence for the subsequent layouts in order to minimize learning effects.

The following criteria were considered significant in job shop operations for the evaluation of layout techniques: (1) cost of labor and materials, (2) time

required to accomplish layout, (3) flexibility of the layout in terms of additional labor cost and time for re-arrangement, (4) educational level required to perform the layout, (5) mental ability required by the layout technician, (6) space perception and utilization attained by the layout technician, and (7) decision influence on management. Factors (1), (2), and (3) were evaluated quantitatively; the remaining factors were analyzed statistically from data obtained by questionnaires distributed to industrial engineering graduate students and professors.

Within the scope of this problem, the conclusions obtained did not specify any one particular technique for universal application to job shop operations. Instead, it was determined that the model technique was best choice where time limitation was the governing factor, while the templet technique was preferred where capital investment had to be minimized. Where time limitation and capital expenditure are of approximately equal importance, the statistical analysis designates the model technique as preferable.

One recommendation is proposed as the result of the review of the space perception data. The results of this review tend to indicate that the qualitative evaluation of this factor is acceptable; however, the development of a quantitative evaluation, in accordance with the procedure suggested, would establish the factor more definitely. It is suggested that the factor of space perception and utilization be defined more accurately in order to quantify its effect on the evaluation.

CHAPTER I

INTRODUCTION

Statement of the problem.--Industry has been constantly exposed to discussions of research on the applications of visual layout techniques and their relative merits as applied to large scale or production type activities. Attempts to apply scientific layout procedures to the smaller industrial activities and job type shops[a] have generally been neglected or discouraged usually because of preconceived opinions of impracticability and excessive expense. It is the purpose of this paper to present a comparative analysis of representative visual plant layout techniques as applied to a job shop. A medium size machine shop has been chosen as the specific design limitation for this research. The objective of the investigation is to determine the most effective method of layout for a typical machine shop.

Area of research.--Since layout in the job shop has generally received only casual attention from the industrial engineering point of view, an attempt will be made to show that at least

[a]The 1951 United States Bureau of Census reports that each of 216,000 manufacturing enterprises (90 per cent of the total) employ 100 persons or less, while the remaining 24,000 establishments each employ more than 100 employees. Manufacturing enterprises of less than 100 employees are usually classified as the smaller businesses.

one of the several methods of visual plant layout would prove feasible and satisfactory for application in a job shop. To limit the many variables which enter into a problem such as this, a medium size job machine shop was selected for the area of study. Based on definitions in Chapter II, the medium size job shop would employ from twenty to fifty persons with machine tools numbering from twenty-five to seventy-five.

The United States Bureau of Census(1) does not classify the machine shop trade into sufficiently fine detail to actually make a definite separation between the small, medium, and large shops. However, the Bureau has prepared the following statistics, shown in Table 1., to show how the machinery industry as a whole (excluding electrical machinery) is divided into employee groups.

Table 1. Machinery Industry

Distribution of Employees	Number of Establish-ments	Number of Employees
1-9	8,432	33,883
10-49	5,825	128,657
50-99	1,341	93,629
100-499	1,696	370,448
500-999	322	226,148
1000+	290	692,558
Total Number	17,906	1,545,323

The machinery industry is then broken down into several categories, one of which is the machine shops. Of the total machinery industry, the machine shop division has 3,112 establishments and 58,160 employees, or 17.4 per cent and 3.8 per cent, respectively. The ratio of establishments to employees is found to be significantly higher than in the other categories, indicating that more shops with few men prevail in the machine shop trade than in allied machinery establishments. This would lead to a general conclusion that machine shop activities predominate in the 1-100 employee class almost exclusively, which therefore establishes the area of machine shop practice.

CHAPTER II

LITERATURE SEARCH

The subject of scientific plant layout is relatively new to the field of industrial engineering. Its appearance became evident during the second quarter of the twentieth century. Practically all the pertinent literature uncovered was cited in case histories of some forty selected periodicals, which excluded several books written during the past eight years. With one or two exceptions, the reference material dealt only with plant layout in production type enterprises of medium and large size with 100 or more employees.

The problems encountered thirty to forty years ago in laying out a plant are closely allied to the problems of present day industry. However, the methods of solving these problems have changed significantly with advancing technology.

With the advent of mass production, synonymous with the introduction of the automobile in the early part of the twentieth century, a change started to take place in the layout procedures of factories. No longer was power for machinery tapped from a central line shaft; no longer were machines and benches permanently positioned(2). The increasing knowledge and intelligent application of safety procedures, motion and time studies, and economic planning, to mention only a few factors, increased the importance of better layout planning techniques.

The development of product and process planning, which was evidenced between 1920-1930, meant that there could evolve more than one or two sound layouts for a new or remodeled factory.(3) In the earlier days of the small job shop, the layout was usually left to the experienced judgment of the shop owner. The owner, who had the ability and inclination to express his thoughts on paper in the form of rough sketches, was significantly more efficient in his planning than those who could not draw or those who had a limited knowledge of machine shop practice.

As shops grew into factories, it also became increasingly important to apply sound judgment and technical knowledge in the initial planning stage. Process charts and flow diagrams first appeared sometime during this transition period; however, no definite date could be established as to when these charts and diagrams were initiated. Undoubtedly, some shop owners had conceived crude variations of these methods which they adopted to their own needs long before these methods became known as industrial planning.

Now that industry had some understanding of what was needed to equip the factories, the lack of an efficient method of planning the placement of machines, men and equipment became more apparent. Trial and error methods were very costly. Drawings were tedious, time consuming, and consequently, expensive. Gradually, the use of cardboard templets and more recently, three dimensional models have answered part of the challenge.

The purpose of these aids to planning is not only to help layout personnel with their problems, but also to facilitate the use of the results of their efforts in convincing management that adoption of the proposed method is desirable. In industry, when new layouts are proposed, or when present layouts are to be altered, management usually has to make the final decision for acceptance or rejection.(4)

Visual layout techniques emanate from several basic methods:

- I. Drawings
  - A. Plan view drafting
    - 1. Blueprints
    - 2. Whiteprints
  - B. Isometric drawings
- II. Templets--two dimensional
  - A. Block templets
  - B. Contour templets
  - C. Variations of contour templets made of plastic or photosensitive film
- III. Models--three dimensional
  - A. Block models
  - B. Contour models
  - C. Prototype models

The drawing technique as outlined above is self-explanatory. Templets exist mainly in two types. The first is the block templet which is nothing more than a rectangular piece of cardboard cut to the overall plan dimensions. The other type is the two dimensional templet; it differs from the former in that it is cut to the general contour (with overruns of moving parts) of the machine or implement and usually has a plan view drawing printed on it.(5)

A variation of the templet that is becoming increasingly popular consists of one-eighth inch transparent plastic photographically printed on one side with the templet of a particular machine. Small magnets imbedded in the plastic serve to hold the templet to a metal layout board.(6)

Scale models are also found in comparable types to those of the templets. In one case, the simple wooden block is used, which gives no indication of contour at all. Contour models do not display all the features of the machine but merely present the general shape, so that the piece can be readily identified. Prototype models are cast of several different materials to produce a detailed replica of the machinery. Sometimes balsa wood is painstakingly carved to the desired accuracy. Colored string is often used with templets as well as models to illustrate the flow of materials throughout the plant.

Recently, three dimensional models have been combined with templets in industrial planning work. The model shows the actual machine in three dimensions while the templet which is placed under the model indicates table travel, projections, and necessary clearances.(7) The use of a 1/4" = 1' grid has been used in most instances, although variations in scale from 1/32" to 1" = 1' have been encountered.

The reproduction of layouts for purposes of display, for records, and for other multi-copy uses has developed with the increased demands for better layout techniques. The foremost method of reproduction is by means of photography. Photostats are used effectively in conjunction with templets, especially with the magnetic plastic templet and the photographic negative templet.(8) White prints or processes similar to ozalid are frequently employed instead of blueprints or photostats. Direct, clear, uniform reproductions may be obtained in this manner from templets without the necessity of any additional preparation. Oftentimes, photographs are taken directly of the layout, be it model or templet. Usually, small sections of the layout are photographed separately to reduce distortion, then the several pictures are pieced together to form a single master print.(9) Once the layout has been reproduced, it can then be dismantled and the components reused for future planning. The prints produced provide a neat, compact record of what action was finally taken or of what possible courses could be followed sometime in the future.

Several efficient methods have been found for filing large and space-consuming layouts when they are not in use. Templets are sometimes stored vertically on sheets of four by eight foot plywood double-hung similar to windows. To obtain a layout of a certain portion of a plant, the counter-balanced board is merely pulled down out of its filing position.(10)

Models are usually stored in sections in drawers of specially built cabinets. They are also stored by making them into a display complete with a transparent shell of the building and a replica of the surrounding areas to provide an attractive exhibit.

One of the conclusions reached after the review of case histories was the significant role played by the chemical industries in the use of three dimensional drawings and models.(11) Construction of pilot plant or unit operations, which required detailed layout of piping, tanks, and other processing apparatus, was aided immeasurably by first building in miniature. Other industries were soon to realize the merits of models as well as templets.

The extensive use of models in the automotive industry is recognized by the intricate detail incorporated in their layouts. The Chrysler Corporation builds models with moving parts, while a typical layout of the Ford Company depicts such details as actual switches mounted on walls and columns.(12)(13) The preceding examples exemplify the status of plant layout in such industries and the goals to which it is aimed.

In an effort to standardize layout procedure, nomenclature, and tools, the American Society of Mechanical Engineers proposed a templet and model code, an abbreviated form of which appears in Appendix A. At the time of this writing, the American Standards Association had not endorsed any layout standards including the afore-mentioned proposal.

Throughout the literature search, the job shop, which differs significantly from the production shop by virtue of small lot size work and extreme process variability,[b] has been generally disregarded with respect to visual layout techniques. Job shop layouts are prepared today in much the same manner as the production shops were planned several decades ago - largely through reliance on the judgment and often, personal whims, of key persons; rather than by the scientific application of formal techniques.

In the following chart, a concensus of several layout techniques applied to the large scale or production type enterprises, is presented for comparison with the results of this paper.(14) Note that the drawing technique is not included, although some of the block templet characteristics are similar.

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[b]The dividing line between production and job shops can be a moot point; however, the definition set forth in the next chapter will be used to avoid ambiguity.

Table 2. Plant Layout Comparison Chart

Block Templet	2-Dimension Templet	3-Dimension Templet	Combination of 2 and 3 Dimension Templet
		Cost	
Low first cost. Can be made by inexperienced personnel.	Requires services of a fairly skilled draftsman with a knowledge of machine tools. First cost considerably higher than for block templet.	Requires skilled model maker if made special. Most models not yet available commercially. Cost of models in quantity not appreciably higher than good 2 dimension templets.	Initial cost of this method combines the cost of 2 dimension templets with 3 dimension models.
		Engineering Value	
Very poor. Does not permit good visualization of layout or effective arrangements.	Good. This type of templet in the hands of a proficient engineer permits very effective layouts. Does not permit easy interpretation of the layout by non-technical personnel.	Good. Makes faster development of equipment arrangements for effective layouts. Helps to 'sell' the layout.	Best. Combines all the merits of 2 dimension templet and 3 dimension model.

Table 2. Plant Layout Comparison Chart (Continued)

Block Templet	2-Dimension Templet	3-Dimension Templet	Combination of 2 and 3 Dimension Templet
		Advantages	
Can be made quickly at very low cost.	Gives a very accurate layout and reduces time required to make final drawings. Clearly indicates actual floor areas required. Serves as a permanent templet when properly made. Greatly reduces possibility of errors as compared to block templets.	Aids visualization of layouts by non-technical personnel. Various schemes can be photographed for comparison studies. Models can be used indefinitely.	Permits highly accurate layouts to be made quickly with complete engineering details. Gives full visualization of layout. Only one set of models necessary to make any number of layouts. Reduces layout and drafting cost.
		Disadvantages	
Does not provide for accuracy of layout, effective arrangements or economical utilization of floor space. Increases drafting time and cost of engineering drawings.	Cost is considerably higher than block templets. Does not provide ease of perceptibility inherent in models. Requires engineers to carry mentally all planning	Does not carry the engineering information provided by the 2 dimension templet. Does not show machine clearances required for operations or services. In-	Highest initial cost of any method.

Table 2. Plant Layout Comparison Chart (Continued)

Block Templet	2-Dimension Templet	3-Dimension Templet	Combination of 2 and 3 Dimension Templet
	Disadvantages (Con'd)		
Fosters discrepancies and errors. Increases overall layout cost.	in the third dimension.	creases drafting time.	

CHAPTER III

JOB SHOP DEFINED

A specific definition of the term "job shop" has not been available to industry. Instead, industry has included in the scope of this term anything from a model shop to something short of the mass production type enterprises characterized by the automobile industries. The General Electric Company, in planning its Engineering Laboratories, set forth the following criteria which for reasons of common viewpoint satisfy the definition of small job shops.(15)

1. Short order jobs--work of usually eight hours or less.
2. Number of employees ranging from six to ten.
3. Number of machine tools ranging from twelve to twenty-five.

Colvin and Stanley limit the small job shop to one employing less than twenty-five persons which, they suggest, reflects the common opinion.(16)

It is notable that only metal working or machine shops are cited for definition. The most common of non-metal trades in the job shop category is the printing industry. The small job printing shop usually employs from one to three workers and has two or three presses. All job shops, however, have several characteristics which will distinguish them from the production type of enterprise:

1. Within a particular industry, job shops will perform more jobs of less quantity than production shops.
2. Job shops have a specific order quantity which is run in one set-up. The job is usually one-of-a-kind and is seldom repeated exactly. Production shops may set up for short quantity runs to fulfill customer schedules. Retooling would be required for each period when a certain quantity is to be delivered.
3. Job shops tend to employ multi-skilled workers as differentiated from the production type industry which employs persons who are trained to operate a specific type of machine, such as a type of punch press or turret lathe. Job shop personnel can be classified in two categories--the mechanic and the assistant mechanic (or trainee), the difference being that the mechanic has mastered the use of all equipment associated with the trade.
4. A variety of work will eventually confront the job shop whereas the production shop, even though it may have to retool for different jobs, will essentially be concerned with the same general type of manufacture it has already experienced. This requires the use of universal type tools in

the job shop and conversely, the production shop would predominately utilize special purpose machinery.

5. Job shop operations employ fewer workers in the small, medium, and large class establishments as compared to the same classifications in production type shops.

6. Mass production techniques are less common and less often observed in a job shop than in production shops primarily because of smaller quantity production. Assembly operations are usually observed intermingled with fabrication operations in job shops.

The qualifications above are qualitative in nature and for that reason are difficult to measure. These definitions are by no means rigid, but are intended to serve as the criteria of a job shop for the purpose of this research.

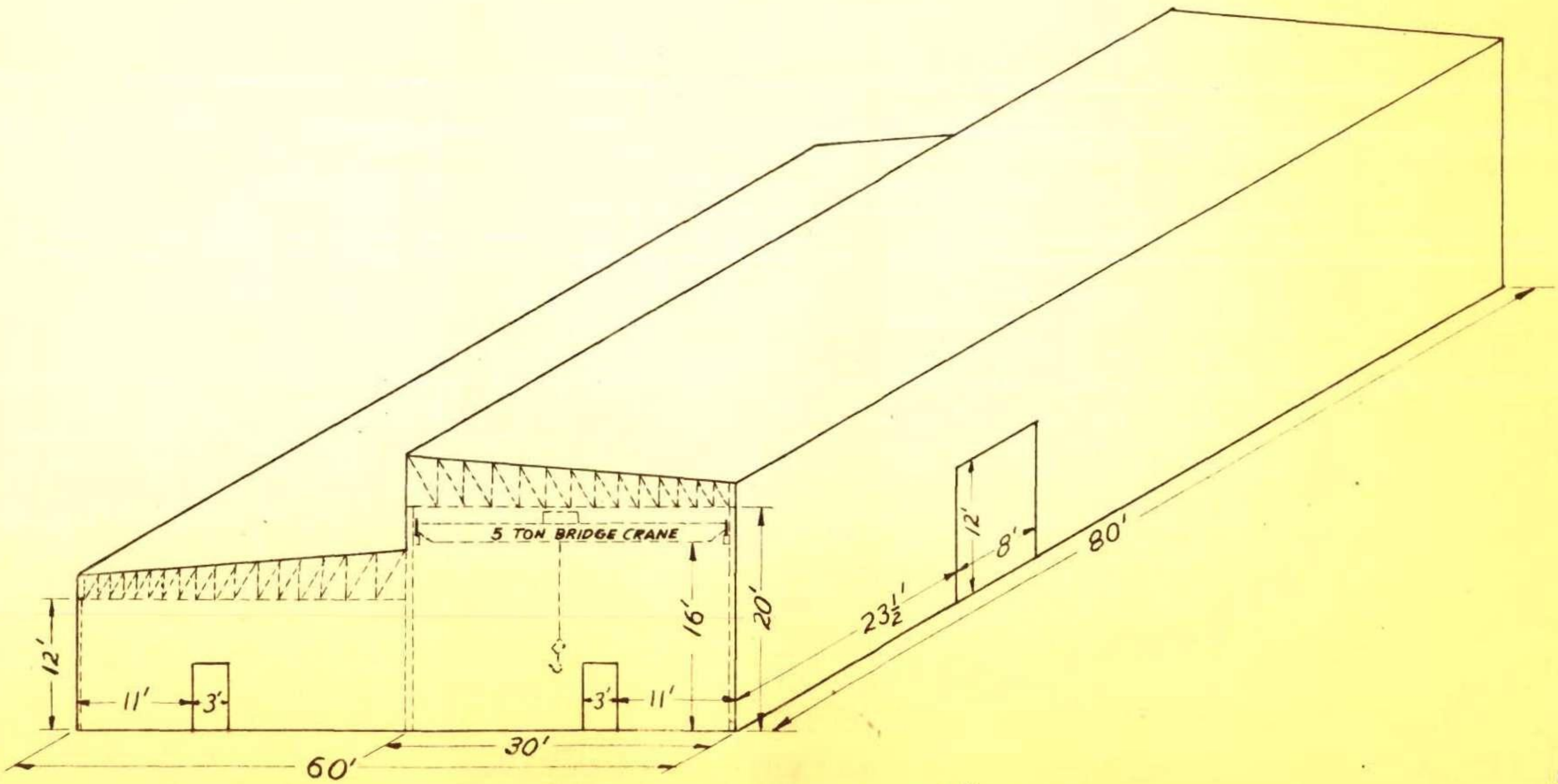
CHAPTER IV

EXPERIMENTAL PROCEDURE

The methods of illustrating layouts have expanded to offer several alternative choices as new materials and tools have been developed. However, all techniques evolve from four basic types: (1) drafting, (2) templets, (3) models, and (4) templets and models. These four fundamental procedures have been selected for application to a representative job machine shop problem.

Ideally, a layout could be described as most efficient if the building were designed around the final product. Unfortunately, industrial planning today is almost wholly confined to structures already in existence or buildings housing the present activities. In order to simulate a typical problem of a medium size job shop, a building sixty feet by eighty feet (columns thirty feet in from eight foot walls, and sixteen feet on centers) was arbitrarily chosen. Figure 1. shows a sketch of the building with approximate dimensions of doors, overhead clearances, etc.

By applying each layout technique to a standardized problem with identical conditions in each case, a comparison can be made on the basis of time, cost, and several other factors as explained in Chapter V. The layout resulting from the first method performed becomes the objective layout for



SKETCH OF MACHINE SHOP $\frac{1}{16}'' = 1'-0''$
Fig. 1

each other method in turn, to facilitate comparison. If each method were used to obtain a layout different from that of each other method, comparison would be hindered by the introduction of this additional variable.

In addition to the selected building dimensions, thirty-five miscellaneous production machines and twenty-three persons were chosen to satisfy the medium size job shop definition. To further supplement the given conditions, Appendix B summarizes all equipment, facilities, and services included in the procedure of each method.

Two premises were made before the procedure was started. First, if any person technically trained in layout techniques were to follow the procedures as outlined in this text, the time ratio of methods would remain the same, or the time differential would be so small as to be negligible, regardless of the degree of experience. Second, the time taken to determine which move is to be made next will be the same regardless of the method used. The time required to make the move physically, however, is definitely known to vary.

The methods used are as follows:

Method I. Drafting (modified block templets drafted)

II. Templets (contour)

III. Models (prototype)

IV. Templets and Models (combination of II. and III. superimposed)

Method II was arbitrarily performed first to develop the standard layout; Method IV was next applied to avoid the necessity of duplicating every move common to both methods; Methods III and I followed. A deliberate effort was made to perform each method at the same pace. Every move performed in Method II was recorded and timed to the nearest minute. Any errors made in Method II were also recorded and followed as the standard procedure by the other methods. This was done in order to control the carry-over learning effect of one method to the other.[c] Before any move was made, the time required to deliberate where a piece of equipment should be placed was recorded, this time being exactly the same irrespective of which method was used first. Appendix C shows the original operation and time data with "think" times listed under Method II but added to "act" times of each method to establish total times for each method.

The given conditions of existing building, facilities required, and equipment were surveyed first. Methods I, II, and IV required rough sketches with dimensions to be made from

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[c]Practice effects were investigated from the psychological viewpoint to determine their importance in this application. A study of recall, reminiscense, retention and memory on individual differences, distribution of practice, and whole or part learning revealed little effect on this study because (1) a relatively small amount of repetition was performed, (2) each trial was repeated by a different method, and (3) sufficient control was retained over the stimuli, procedure, and response to negate the practice effects.(17)(18)

manufacturers' catalogs or from the existing equipment. Templets drawn in India ink from these sketches followed the proposed American Society of Mechanical Engineers standards as outlined in Appendix A. It was not necessary, however, to include all the information on the templets because of the variety and singularity of the machine tools.

Following normal layout procedure, regardless of the technique applied, a sketch was made of the building floor plan, noting exits and obstructions. It is at this point that the general areas of each service or facility were determined. For example, due to the travel of crane over the right half of the building, the location of heavy machinery and fabrication should be within this area; the supply room should be close to the receiving door, whereas the office should be close to the front entrance as well as near the working area. In making the sketch, a pre-grouping of the machines in each area was roughly drawn as shown in Figure 2.[d]

No attempt will be made to defend the actual arrangement of equipment and facilities although reasonable layout tolerances were observed.

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[d]In this case, equipment was laid out according to a pattern developed by the author at the machine shop of the Georgia Institute of Technology Engineering Experiment Station.(19) The lathes, milling machines, and benches were found to be closely related by collecting information from past work orders. (See Appendix B). This differs from the conventional colony type layout usually employed because of so-called unpredictable product and process variation.

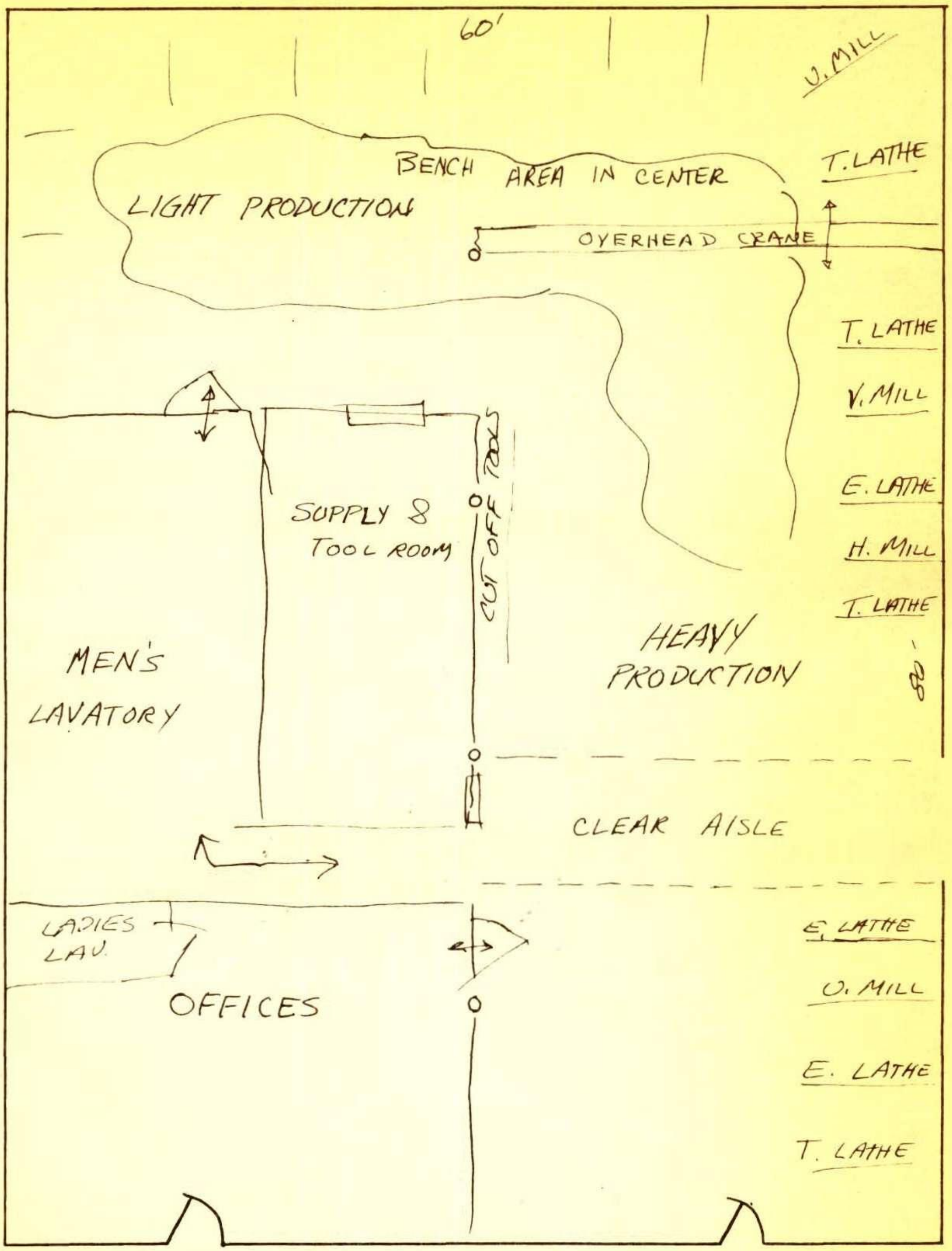
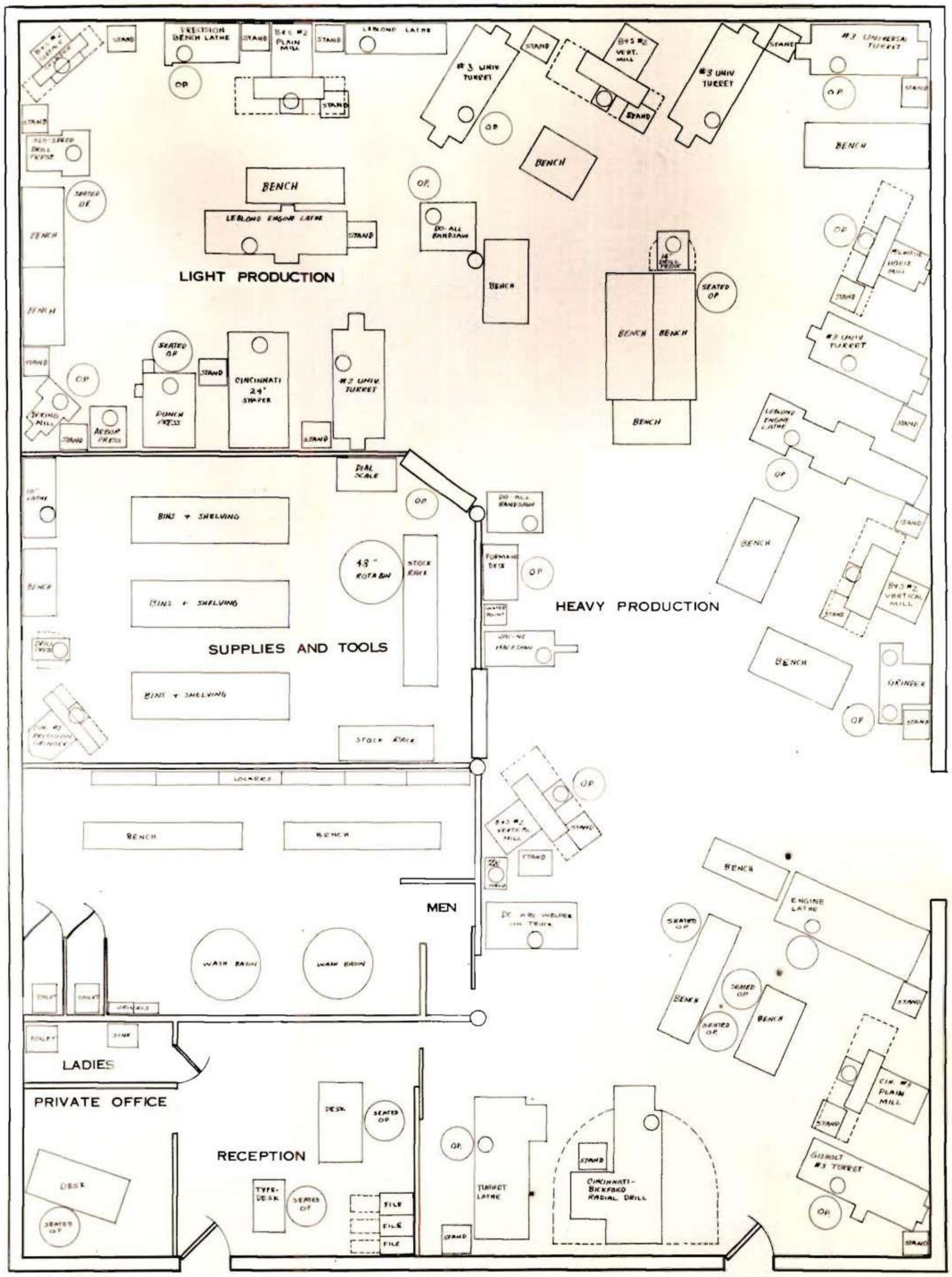


Fig. 2 ROUGH SKETCH OF FLOOR PLAN AND PRELIMINARY EQUIPMENT AND FACILITY AREAS

After the building outline was established, the production equipment was plotted in the general areas previously assigned. Rearrangement of the equipment followed under the influence of process flow, materials handling, aisle space, and similar layout factors. The supply and tool room followed in much the same procedure as did the men's lavatory and the offices. Machinery units left out of the layout until the facilities were temporarily established, were now inserted in the space alloted. Rearrangement of equipment and partitions needed after the layout was tentatively completed were made as discrepancies were found. Again, during the final stages of the layout (operations 13 A, B, and D of Appendix C), changes to provide a better arrangement were found necessary. Construction of the bridge crane system was confined to Methods III and IV as the other methods were not suitable for showing overhanging projections. Plan view photographs of each method are shown on the following pages.



METHOD I - DRAFTING

Fig. 3

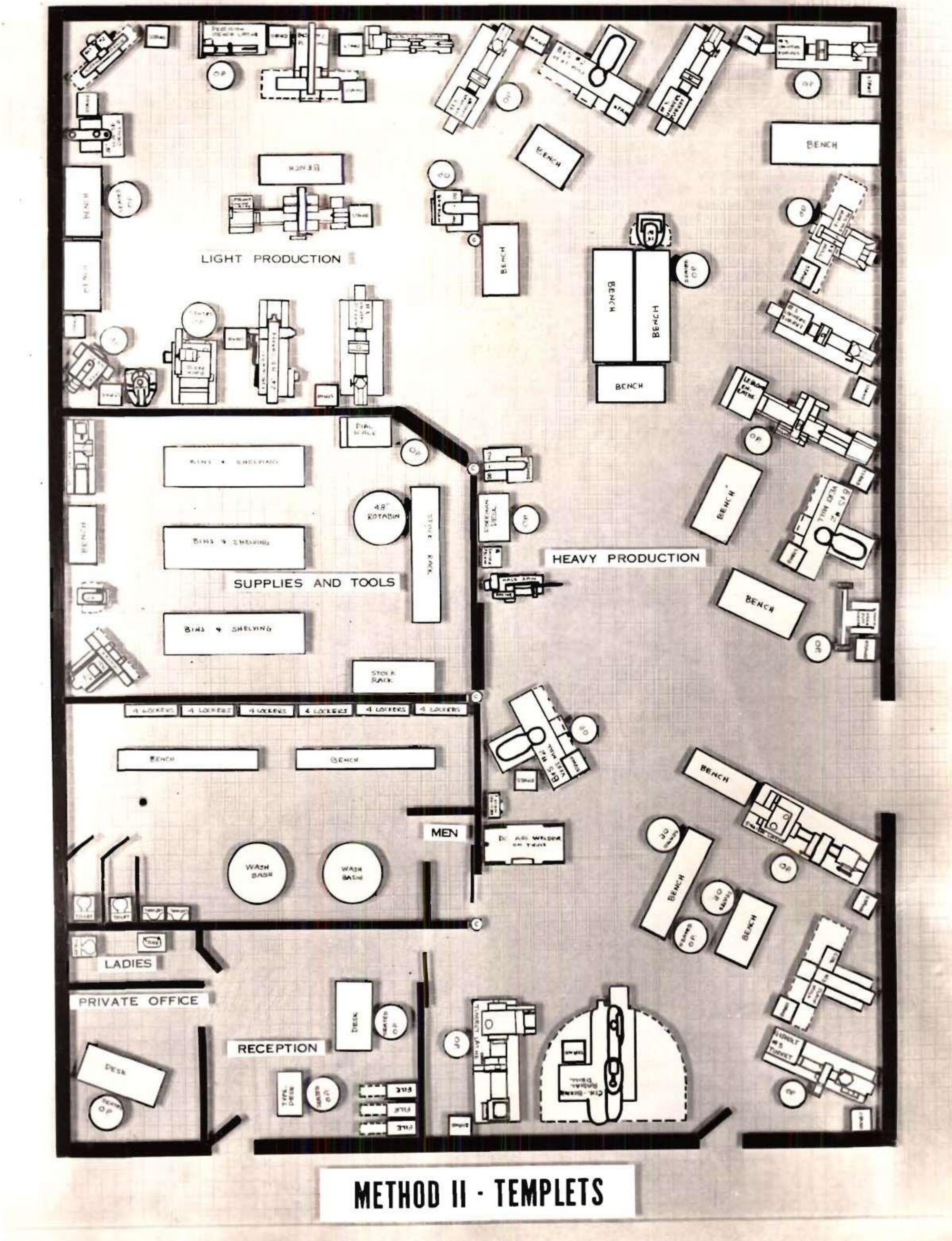

LIGHT PRODUCTION
SUPPLIES AND TOOLS
HEAVY PRODUCTION
BENCH
BINS & SHELVING
STOCK RACK
4 LOCKERS
WASH BASIN
MEN
LADIES
PRIVATE OFFICE
RECEPTION
DESK
METHOD II - TEMPLETS

Fig. 4

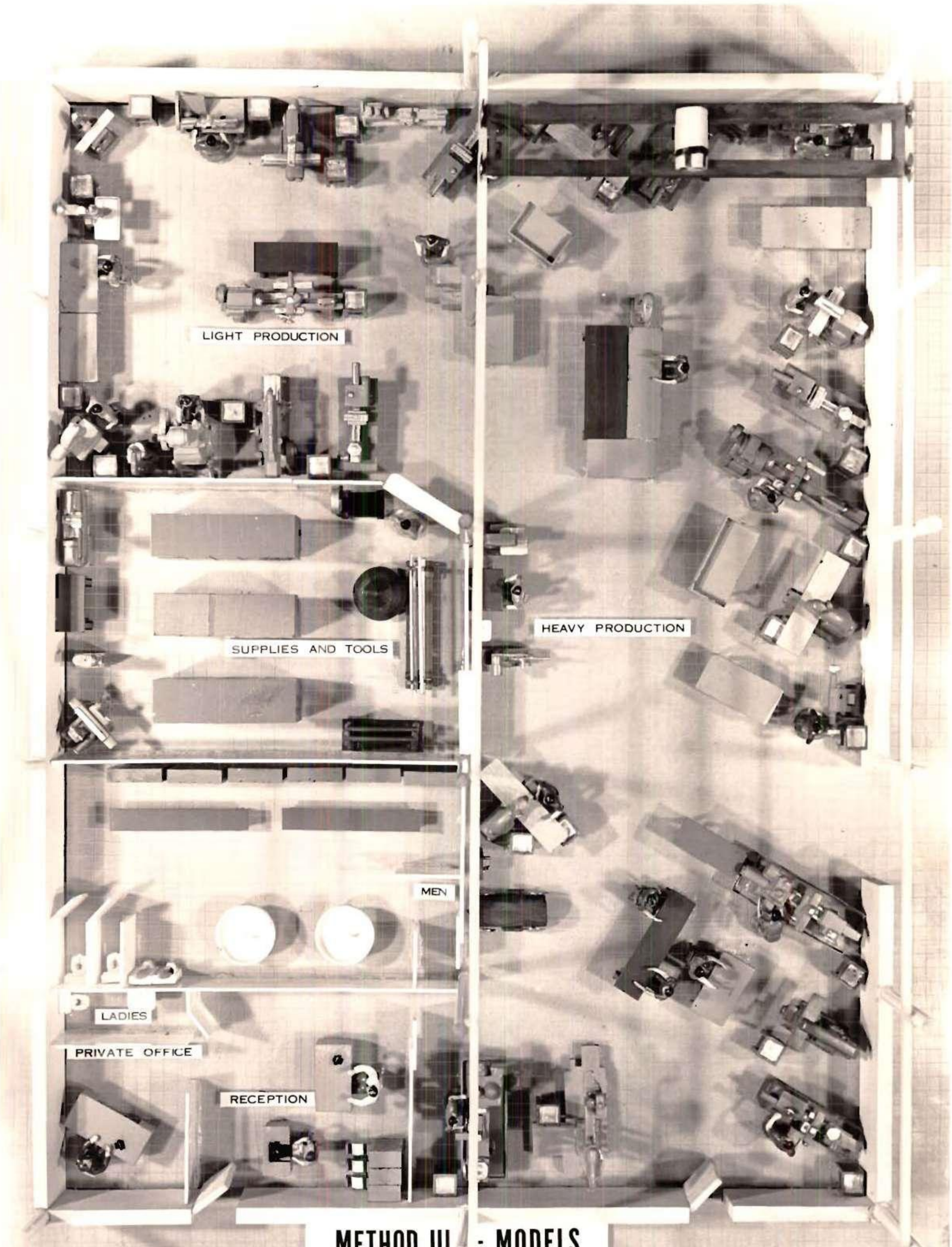

LIGHT PRODUCTION
SUPPLIES AND TOOLS
HEAVY PRODUCTION
MEN
LADIES
PRIVATE OFFICE
RECEPTION
METHOD III - MODELS

Fig. 5


LIGHT PRODUCTION
SUPPLIES AND TOOLS
HEAVY PRODUCTION
MEN
LADIES
PRIVATE OFFICE
RECEPTION
METHOD IV - TEMPLETS AND MODELS

Fig. 6

CHAPTER V

EVALUATION AND RESULTS

The evaluation of layout methods consisted of a combination of quantitative and qualitative studies.

Quantitative analysis.--Included in the quantitative evaluation are the cost of the layout in terms of labor and material, the time required to perform the layout, and the degree of flexibility in creating the layout and making changes.

The assignment of a definite monetary value to labor is a difficult task as sections of the layout may be performed by non-technical personnel with a $200/month salary, or by professional engineers with $900/month salary. For purposes of comparison, the typical salary of an industrial engineering trained supervisor (about $600/month or $3.50/hour) was used for all operations in each method. Cited costs of material were purchase prices at local architects' supply houses or quotations from "Visual" Plant Layouts Inc., Oakmont, Pennsylvania. Time and material data were prepared in the following tables, summarized from Appendix C.

Flexibility was determined by computing the time and expense involved in rearranging the layout as shown by Operations 6B, 7B, 8B, 9B, 10B, 11, and 13E in Table 5.

Table 3. Cost Analysis

Method	Labor Cost at $3.50/Hr.	Material	Material Cost	Total Cost	Cost Ratio
I	$69.23	None	None	$69.23	1.30
II	51.62	Roll of 1/4" Scotch Tape	$1.15		
		1 1/2' x 2'-1/4" grid sheet	.50		
			1.65	53.27	1
III	24.88	Roll of 1/4" Scotch Tape	1.15		
		1 1/2' x 2'-1/4" grid Lucite board	18.00		
		15 Lucite columns	11.25		
		12" outside walls	7.00		
		4" inside partitions	7.50		
		130 models	312.00		
		Crane system(hand made)	1.50		
			358.40	383.28	7.19
IV	61.95	Same materials as in Method III	358.40	420.35	7.90

Table 4. Time Element

	Method			
	I	II	III	IV
Time in Hours	19.78	14.75	7.11	17.70
Time Ratio	2.78	2.08	1.00	2.49

By substituting variations of each method significantly different results appeared. For example, if ready-made templets were purchased instead of made in Method II, the cost of time in Table 3. decreased to $23.63 and the cost of material increased to $55.50, presenting a new total of $79.13.[e] The time in Table 4. decreased by eight hours. A similar decrease in labor cost, increase in material cost and decrease in time was evident in Method IV. Of course, these variations are contingent on the availability of the exact templets needed.

If the crane assembly in Methods III and IV could be purchased, the cost of these methods would be decreased in time and increased in material; these layouts would have afforded a better comparison to Methods I and II which cannot satisfactorily illustrate the crane assembly.

<u>Quantitative results</u>.--The quantitative analysis shows Method II to be favored significantly in terms of cost and flexibility, but only second best in time. Accordingly,

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[e]Quoted from "Visual" Plant Layouts Inc., Oakmont, Pa.

Table 5. Flexibility

Operation	Method I		Method II		Method III		Method IV	
	Time in Hours	Labor Cost $	Time in Hours	Labor Cost $	Time in Hours	Labor Cost $	Time in Hours	Labor Cost $
6B	2.63	9.21	0.35	1.23	0.75	2.63	0.35	1.23
7B	0.85	2.97	0.25	0.87	0.47	1.65	0.25	0.87
8B	0.78	2.73	0.20	0.70	0.42	1.47	0.20	0.70
9B	0.73	2.55	0.30	1.05	0.42	1.47	0.20	1.05
10B	1.23	4.31	0.48	1.68	0.68	2.38	0.48	1.68
11	0.25	0.87	*	*	*	*	*	*
13E	2.88	10.08	0.24	0.84	0.59	2.07	0.78	2.73
Total	9.35	$32.72	1.82	$6.37	3.33	$11.67	2.36	$8.26
Ratio	5.14		1		1.83		1.30	

*Too small to be significant

Method II would be chosen; it would be selected on a sounder basis if the assumption could be made that time, in terms of over-time hours and/or purchased templets, could be more easily procured in a job shop than could capital for investment. The 2.08:1 time ratio would then overbalance the 1:7.19 cost ratio in Methods II and III.

Qualitative analysis.--Four factors which are difficult of precise measurement enter into the selection of the best layout technique for the job shop, namely; (1) the educational level required to perform the layout, (2) the mental effort required to do the layout, (3) the space perception and utilization attained by the layout technician, and (4) the decision influence on management. The educational level factor would question the use of the layout techniques with the equivalent ability of a technician, engineer, executive, or even a mechanic. The second consideration would weigh the ratio of self evident procedure to matters requiring deep thought and constant searching. Given a specific length of time to perform a layout, space perception and utilization would test the relative effectiveness of each technique. The influence decision on management questions the comprehensibility of the respective results obtained through use of techniques by the policy-makers within the industrial enterprise.

In order to arrive at some significant conclusion, a form of decision theory was employed to weigh the above factors.(20) In essence, this theory proposes that for each problem there can be selected several methods of solution (M_i) which will in turn result in several possible actions (A_j). The probability (P_{ij} - i methods with j possible actions) that a method will produce a certain action is one of the considerations in making the decision which is the choice of the best layout method. The chances of success in any situation must be estimated; however, the best decision will not always depend on the highest probability attained since the resulting actions (A_j) should be assigned ranked values in accordance with an individual's preference. By assigning A_j with an evaluation factor (E_j - a measure of individual preference) the best decision may now be determined by the method which maximizes $P_{ij}E_j$. If two methods of solution (M_1 and M_2) were to be decided upon, each producing three results (A_1, A_2, and A_3), selection of one by ranking alone might produce one decision whereas closer investigation by assigning values (E_1, E_2, and E_3) to the results and weighing each E_j in each probability could produce a different decision--a more accurate one. For example:

Table 6. Decision Theory Evaluation

	A_1 ($E_1 = 6$)	A_2 ($E_2 = 5$)	A_3 ($E_3 = 1$)
M_1	$P_{11} = 10$	$P_{12} = 2$	$P_{13} = 3$
M_2	$P_{21} = 3$	$P_{22} = 7$	$P_{23} = 8$

in Table 6. where $\Sigma P_i(M_1) = 15$ and $\Sigma P_i(M_2) = 18$, the choice would lean toward M_2. However, by assigning E_j to each A_j and weighting these values, the results are:

$$
\begin{aligned}
\Sigma P_{ij}(M_1) &= P_{11}E_1 + P_{12}E_2 + P_{13}E_3 \\
&= (60) + (10) + (3) \\
&= 73 \\
\Sigma P_{ij}(M_2) &= P_{21}E_1 + P_{22}E_2 + P_{23}E_3 \\
&= (18) + (35) + (8) \\
&= 61
\end{aligned}
$$

This is a reversal of the decision in favor of M_1; the latter case being more accurate.

The P_{ij} is determined by the individual's estimate of how well the A_j will satisfy the given situation (or its effectiveness) with comparison to other P_{ij}'s, etc., given a selected linear scale. The E_j is determined by first ranking the A_j in order of relative importance, without consideration of value. On a linear scale, values (E_j) are then tentatively assigned to the A_j. Starting with A_1, the values E_2, E_3, $\cdots E_k$ are checked for their relative rank with E_1 by questioning the preference of A_1 over the combination $A_2 + A_3 + \cdots A_k$. If $A_1 <, =, > A_2 + A_3 + A_k$, then the E_2, E_3, $\cdots E_k$ must be altered arithmetically to satisfy the decision. A_2 is chosen next to test the relationship of $A_3, \cdots A_k$, and so forth. When numerical changes are made, previous relationships should not be disturbed unless in the application of this process the reasoning is changed.

Application of the decision theory was accomplished by asking ten graduate industrial engineering students with little layout experience and four industrial engineering professors with moderate but not extensive experience to rate the probabilities of (A_1) educational level, (A_2) mental effort, (A_3) space perception, and (A_4) decision influence under the possible methods (M_1) drafting, (M_2) templets, (M_3) models, and (M_4) templets and models. They were then asked to evaluate A_1, A_2, A_3, and A_4 by assigning values E_1, E_2, E_3, and E_4 similar to the previous example. For a more detailed account of the information asked, a copy of data evaluation survey is included in Appendix D together with the results of each participant.

The computation procedure of the solicited data appears on data evaluation sheet number one only, as all other procedures are similar. Since the individual raw evaluations differed widely in scale, results were transformed into a per cent value of 100 for comparison.

A tabulation of the adjusted results is shown in Table 7. A statistical analysis of the results of each method is shown in Table 8. where $\overline{X}$ is the arithmetic average and s is the unbiased estimate of the standard deviation of the fourteen determinations for each method.

The first hypothesis tested is that the variances of the four methods are homogeneous. In terms of the data shown in Table 8., this would imply that the results for each

Table 7. Summation of Data Evaluation

Participant	Method I	Method II	Method III	Method IV
1.	10.5	20.3	32.1	37.1
2.	17.1	21.0	31.3	30.5
3.	8.6	15.5	25.4	50.4
4.	12.9	27.9	22.0	37.0
5.	12.9	24.4	29.7	33.0
6.	4.6	26.8	42.0	26.6
7.	0	21.9	36.3	41.7
8.	14.0	16.1	41.7	28.2
9.	4.5	18.6	35.7	41.2
10.	24.3	23.3	26.1	26.3
11.	13.1	19.8	28.2	38.9
12.	15.2	17.7	31.6	25.4
13.	13.7	25.2	29.7	31.4
14.	10.3	18.5	34.2	37.0

Table 8. Statistical Tabulation

	Method I	Method II	Method III	Method IV
$\bar{X}$	11.5	21.2	31.9	35.3
s	6.0	3.9	5.8	6.7

method had the same dispersion or variability. This hypothesis was tested statistically by the use of Bartlett's Test.(21) The results of this test indicated that this hypothesis of homogeneity of variances is reasonable, since the F value obtained did not approach significance. The calculations for all tests can be found in Appendix E.

Since the hypothesis of equal variances is accepted, the method preference shown by the $\bar{X}$'s was tested for significance. The second hypothesis made is that each $\bar{X}$ is not significantly different from the others, or no one method was preferred over any other. Methods III and IV with the closest preference ratings were selected first using Student's t distribution(22) for testing the difference between pairs of sample means. The sample value for t was 1.48, a value which is not considered statistically significant. Methods I and II having the next largest difference of $\bar{X}$'s were then tested. The sample value for t was 5.07, a value which is significant at less than the 0.25 per cent level. Since the differences of the remaining combinations of $\bar{X}$'s are larger than the case just cited, all other differences are significant.

Qualitative results.--The conclusions reached in the qualitative analysis section are that (1) Method I is the poorest choice, (2) Method II is a better selection than Method I, and (3) Methods III and IV are best. Although Method IV does have a higher $\bar{X}$ than Method III, this difference was not found to be statistically significant whereas the differences of the other $\bar{X}$'s were found to be significant.

CHAPTER VI

CONCLUSIONS

The results of each evaluation analysis specify different optimum methods. If the two evaluations had resolved into the same answer, the reinforcement of one solution upon the other would have left no doubt as to the best selection.

Upon inspection of the space perception and utilization data, it was found that the premise of equal "think" times does not necessarily hold true because of the varied assignment of values in each method. It is assumed that by using any layout technique the final space utilization would be the same, as designed in the experiment. This means that space perception must vary from one method to the next which also infers varying "think" times. "Think" times for Method II, the initial procedure, would remain the same while Method I "think" times would be increased because of the low values assigned "C." in the evaluation data survey sheet. Conversely, "think" times for Methods III and IV would be decreased because of the high values assigned "C.".

The overall time elements would be changed correspondingly, decreasing the costs of Methods III and IV while increasing the time ratio of Method III with II. This would possibly lead to the conclusion that Methods III and IV could be preferred quantitatively as well as qualitatively thereby selecting Methods III and/or IV as the best choice.

In view of the previous considerations, three general statements can be postulated. (1) For machine shop layouts where time limitation is the most important factor, Method III, the model technique, is the best choice. (2) For machine shop layouts where capital investment must be minimized, Method II, the templet technique, is most satisfactory. (3) Where there is a question of using either Method II or III, Method III should be selected because of reinforcement by the qualitative analysis.

CHAPTER VII

RECOMMENDATIONS

Although it was qualitatively determined that space perception varies with the "think" time required in the several layout techniques, it is the opinion of the author that these times would not be significantly changed so as to invalidate the procedure or conclusions presented in this paper. An effort should be made to quantify the true effect of this phenomenon for the purpose of accepting or rejecting the previous conclusions.

Rather than perform a duplicate test of the problem in this work, it is suggested that several different problems be designed, each to be performed only once and each problem to be solved with a different method. In this way, any person performing the layout would not use any method more than once, nor would he work the same problem more than once.

For purpose of comparison, participants with as near the same background in layout experience must be selected. They should be timed independently to sufficiently distinguish "think" times from other time. A complete statistical analysis could be used to evaluate the results.

APPENDIX A

A CONDENSED FORM OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS PROPOSED CODE FOR STANDARDIZING LAYOUT NOMENCLATURE

A CONDENSED FORM OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

PROPOSED CODE FOR STANDARDIZING LAYOUT NOMENCLATURE (23)

Templets.--The standard covers two-dimensional, one-plane templets and three-dimensional equipment models.

Templet scale is 1/4 in. equals 1 ft., U.S. measure. This scale is standard with architects, engineers, furniture and equipment manufacturers, etc., for planning purposes. Equipment outlines are those which would be made around the periphery of a piece of equipment by a plumb line held 7 ft. above the floor, and passed around the outline of the machine. Projections such as wheels, handles, etc., are separately indicated as details not in the periphery.

Details on the templet are those necessary to make it distinguishable and to locate important points. Kinds and relative weights of lines used are:

Fixed outline of machine tool or equipment	Thick solid line
Detail parts and substructures	Thin solid line
Clearances for moving parts of machine tool or equipment	Thick dash line
Overhead or underground elements, foundation pits, service clearances and other elements important to the templet	Medium dot-and-dash line
Center lines	Thin dot-and-dash line

Clearances for movable parts, access and operation are shown in dash lines. Templets do not include storage, service or other space.

Interferences are indicated by medium dot-and-dash lines and are included in final drawings.

Data on the templets includes: over-all length, width, height, including travel clearance but not operator or feed clearances. Weight and horsepower are given.

Specifications for identification are: model or style, name, size, user company identification marks or numbers.

Operator position is shown by a short heavy arrow. Other data included are controls, service provisions, power connection points, and similar indicators of necessary auxiliary operating facilities.

Templets should be printed on 110 lb., or more, index bristol or similar durable stock. It is preferable to use colored stock:

Machine tools and other operating or production equipment............................Salmon

Office equipment and standard factory equipment-bins, racks, locker room equipment, toilet and washroom facilities...............Green

Materials handling equipment............Yellow

Auxiliaries-pallets, skids, tote boxes, trays, pans, etc.....................Red

Models.--Three dimensional scale representations of equipment and facilities, called models, are made from wood, metal or plastic by appropriate processes, including tool and machine fashioning, die casting, and plastic production methods.

The scale is the same as that for templets, 1/4 in. equals 1 ft., U. S. measure.

Details included are those sufficient, without distortion, to identify the model and show its important structural and operating features for ready identification of the equipment and indication of its operating requirements so far as plant layout is concerned. Control points and hazard areas are shown, with all controls and operating or moving parts located in neutral position, no moving parts being designed into the model unless it is impossible to show them in any other way.

Models are made in finishes and colors as near as possible to the actual item represented-including multiple finishes, as in office furniture.

Machine-tool model finishes should follow the recommendations of the National Machine Tool Builders Association. Machined surfaces can be shown by aluminum paint.

Control points should be shown by light buff paint, conforming to the present-day practices for greater visibility and safety. The practice of the individual company should be followed where models are used exclusively for a company.

Allowances and clearances should not be exaggerated. Accompanying templets should show these allowances for extreme operating and service conditions, but should not include any operator or facilities allowances, as stated above under discussion of templets. These accompanying templets should carry at least name or description and model number, and, if possible, type, size, maximum dimensions, certer lines, weight, etc., and data on overhead and underfloor requirements.

Models should be durable, not easily damaged, have a lasting finish, and have sufficient weight to stay in position when placed, or be equipped with holes in the base for insertion of fastening pins.

All necessary identification markings--name, number, size, description, etc. should be given in abbreviated form and in the most suitable place.

Models should be so designed as to be used with accompanying standard templets for the identical equipment. This provision facilitates drawing the layout on the floor plan.

APPENDIX B

EQUIPMENT LIST - GIVEN CONDITIONS

EQUIPMENT LIST - GIVEN CONDITIONS

Production Area

12-Lathes
- 5-#3 Universal Turret
- 1-Gisholt #3 Turret
- 3-LeBlond Engine, 10", 12", 16"
- 1-14" Warner and Swasey Engine
- 1-14" Pratt and Whitney Engine
- 1-Rivett Precision (Cabinet)

6-Milling Machines
- 3-Brown and Sharpe #2 Vertical
- 1-Milwaukee Horizontal
- 1-Cincinnati #3 Plain
- 1-Brown and Sharpe #2 Plain

1-Cincinnati 24" Shaper

4-Drill Presses
- 1-Cincinnati-Bickford Radial
- 1-8" Sho-speed
- 1-14" Delta Pedestal
- 1-Knight Boring Mill

1-22 Ton L & J Punch Press

2-Grinders
- 1-Brown and Sharpe #2 Surface
- 1-Hammond Heavy Duty Tool

1-Racine Hack Saw W3BX

2-Do-All HP-36 Band Saws

2-Welders
- 1-Direct Current Arc on truck 3' x 6' x 4'
- 1-Heliarc 1' x 2' x 3'

1-Denison Arbor Press

14-Benches
- 6-3' x 5'
- 2-3' x 8'
- 1-2 1/2' x 8'
- 1-2' x 8'
- 2-3' x 6'
- 1-5' x 4'
- 1-2' x 5'

EQUIPMENT LIST - GIVEN CONDITIONS (CONTINUED)

Production Area (Con'd)

1-Water Fountain

26-Machine Stands 1 1/2' x 2' x 3'

1-Foreman's Desk

1-5 Ton Bridge Crane Assembly

Supply and Tool Room

3-3' x 10' x 6' Bins and Shelving

1-48" Rotabin

1-Bench 2' x 4'

1-Dial Platform Scale 2' x 3 1/2' x 3'

1-12" Delta Pedestal Drill Press

1-10" South Bend Lathe

1-Cincinnati #2 Precision Grinder

2-Stock Racks
1-2 1/2' x 6' x 6'
1-2' x 9 1/2' x 6'

Men's Lavatory

2-Toilets

2-Urinals

2-Circular 4' Wash Basins

2-Benches 1 1/2' x 10'

6-Lockers 1' x 4'

Ladies' Lavatory

1-Toilet

1-Sink

EQUIPMENT LIST - GIVEN CONDITIONS (CONTINUED)

Offices

3-Desks
  1-Typist
  1-60"
  1-72"

3-Letter Files

----

23 Personnel (or operators)
  3-Office
  1-Supply and Tool Room
  19-Production

APPENDIX C

PROCEDURE DATA

PROCEDURE DATA

METHOD (Times in Hours and Minutes)

Operation	I Act	I Total	II Think	II Act	II Total	III Act	III Total	IV Act	IV Total
1. Review given conditions of problem; list requirements for equipment and services.	20	20		20	20	20	20	20	20
2. Sketch and measure tools and equipment from manufacturers catalogs or actual facilities.	3:30	3:30		3:30	3:30	3:30	3:30	3:30	3:30
3. Draw templets, ink in contours and controls, and cut out.				8:00	8:00			8:00	8:00
4. Draw sketch of building floor plan; determine general service areas with regard for building design; sketch approximate grouping of allied equipment within areas.	35	35		35	35	35	35	35	35

PROCEDURE DATA (CONTINUED)

	I		II			III		IV	
Operation	Act	Total	Think	Act	Total	Act	Total	Act	Total
5. A. Draw building outline with existing doors and columns.	20	20							
B. Tape in building outline with existing doors and columns.				07	07			07	07
C. Cut plastic walls to length and glue to baseboard to form building outline; glue in columns and doors.						59	59	59	59
Sub-Total:	20	20		07	07	59	59	1:06	1:06
6. A. Draw or place production tools with allied equipment in general areas bearing in mind the overall arrangement required in existing facilities.	2:03	2:03		04	04	11	11	04	04
B. Rearrange the following equipment (with machine stands) in the given order:									

PROCEDURE DATA (CONTINUED)

Operation	I Act	I Total	II Think	II Act	II Total	III Act	III Total	IV Act	IV Total
1) LeBlond Engine Lathe with Brown and Sharpe #2 Vertical mill.									
2) Turret lathe with #3 heavy duty grinder.									
3) Two #3 Universal Turret lathes with two Brown and Sharpe #2 Vertical mills.									
4) Small LeBlond lathe with boring mill.									
5) Brown and Sharpe #2 Vertical mill with turret lathe.									
6) #3 Turret lathe with Brown and Sharpe #3 Plain mill.									
7) Remove from layout: Boring mill									

PROCEDURE DATA (CONTINUED)

Operation	I Act	I Total	II Think	II Act	II Total	III Act	III Total	IV Act	IV Total
LeBlond- Engine lathe Turret lathe Radial Drill Hack Saw 2-Do-all saws B&S #2 Verti- cal mill Forman's desk 2-welders 8) Brown and Sharpe Surface grinder. 9) Cincinnati Shaper with bench 10) Punch Press with Slo-speed Drill press 11) 3-benches 12) 5-benches	2:23	2:38	15	06	21	30	45	06	21
Sub-Total:	4:26	4:41	15	10	25	41	56	10	25
7. A. Draw or place Supply and Tool Room equipment in general area.	16	16		02	02	05	05	02	02
B. Rearrange the following equipment in the given order:									

PROCEDURE DATA (CONTINUED)

Operation	I		II			III		IV	
	Act	Total	Think	Act	Total	Act	Total	Act	Total
1) Shelving and racks									
2) Shelving and racks									
3) Stock rack									
4) Rotabin									
5) Draw or place temporary partitions									
6) 10" lathe with bench									
7) Grinder with Drill Press									
8) Move inside partition									
9) Stock rack	41	51	10	05	15	18	28	05	15
Sub-Total:	57	1:07	10	07	17	23	33	07	17
8. A. Draw or place men's lavatory equipment in general area.	17	17		01	01	02	02	01	01
B. Rearrange the following equipment in the given order:									
1) Toilets with urinals									
2) Wash basin									
3) Wash basin back to original place									

PROCEDURE DATA (CONTINUED)

Operation	I Act	I Total	II Think	II Act	II Total	III Act	III Total	IV Act	IV Total
4) Draw or place in temporary partitions									
5) Move partition with toilets, urinals and basins.	37	47	10	02	12	15	25	02	12
Sub-Total:	54	1:04	10	03	13	17	27	03	13
9. A. Draw or place offices and ladies' lavatory equipment in general area.	12	12		01	01	02	02	01	01
B. Rearrange the following equipment in the given order:									
1) All equipment for both offices									
2) Draw or place in temporary partitions									
3) Desk									
4) Typewriter desk with 3 files									
5) Desk	29	44	15	03	18	10	25	03	18
Sub-Total:	41	56	15	04	19	12	27	04	19

PROCEDURE DATA (CONTINUED)

Operation	I Act	I Total	II Think	II Act	II Total	III Act	III Total	IV Act	IV Total
10. A. Draw or place balance of production equipment (from 6-B-7) in proper area.	33	33		01	01	02	02	01	01
B. Rearrange the following equipment in the given order: 1) Shaper 2) Punch press 3) Arbor press 4) Slo-speed Drill press 5) Fountain 6) Heli-arc Welder 7) D.C. Arc Welder 8) Hack saw with foreman's desk 9) Do-all Band saw 10) 4 benches 11) Fountain with 2 welders and hack saw	54	1:14	20	09	29	21	41	09	29
Sub-Total:	1:27	1:47	20	10	30	23	43	10	30
11. Switch Basins, toilets, and urinals with partitions	15	15		01	01	01	01	01	01

PRODUCTION DATA (CONTINUED)

Operation	I Act	I Total	II Think	II Act	II Total	III Act	III Total	IV Act	IV Total
12. Draw or place operators in position.	04	04		01	01	01	01	01	01
13. A. Draw all lines in heavy.	1:27	1:27							
B. Glue down all templets and permanent partitions.				10	10				
C. Put models in place.								08	08
D. Cut partitions and doors from plastic and glue in position.						40	40	40	40
E. Rearrange the following equipment (with operators and stands) in the given order: 1) Rotabin with dial scale 2) Stock rack 3) 5 benches 4) 14" Drill press 5) 4 benches 6) Small Engine lathe 7) Do-All Band saw with Drill press 8) Boring mill with Arbor press 9) Shaper with #3 Turret lathe									

PRODUCTION DATA (CONTINUED)

Operation	I Act	I Total	II Think	II Act	II Total	III Act	III Total	IV Act	IV Total
10) Precision Lathe with small LeBlond lathe 11) Punch press with B&S #2 Vertical mill	2:37	2:52	15	02	17	20	35	32	47
Sub-Total:	4:04	4:19	15	12	27	1:00	1:15	1:20	1:35
14. Construct bridge crane system from balsa wood, wire, and thumb-tacks; paint with tempera; and install.						50	50	50	50
15. Print equipment nomenclature on drawing.	50	50							
TOTAL TIMES:		19:47 = 19.78 Hours			14:45 = 14.75 Hours		7:07 = 7.11 Hours		17:42 = 17.70 Hours

APPENDIX D

DATA EVALUATION SURVEY AND COMPUTATIONS

DATA EVALUATION SURVEY

In order to complete data needed for a thesis on plant layout, it is requested that you read the following instructions and comply with them to the best of your ability. Your assistance will be greatly appreciated.

Four methods of plant layout techniques are to be evaluated:

METHOD

I. Drafting (Block Form)

II. Templets (Contour)

III. Models (Prototype)

IV. Templets and Models (Superimposed)

The following criteria will be used for evaluation:

EVALUATION (E)

A. Education level required to perform the layout

B. Mental effort required to do the layout

C. Space perception and utilization attained by layout engineer

D. Decision influence on management

I. In the space provided below, rank the effectiveness of "A" in Methods I, II, III, and IV by assigning the method it best satisfies with a value of "10"*, decreasing the values of the remaining methods with "0" as the possible lower limit. Repeat this procedure with B, C, and D. Finish this section before reading II.

* Best satisfaction of A and B would mean least required

Method	I	II	III	IV
EVALUATION				
A				
B				
C				
D				

II. As a separate procedure, rank A, B, C, and D in order of importance with a tentative value of "10" given to

DATA EVALUATION SURVEY (CONTINUED)

the most important, and smaller values given the rest, according to their relative importance ("0" is the lower limit). Space is provided below. The most important evaluation will be termed E_1, next important E_2, etc. Compare E_1 with $E_2 + E_3 + E_4$. If E_1 is preferred over the sum of the others, the values should be adjusted so that $E_1 > E_2 + E_3 + E_4$. Similarly, the values would be adjusted if $E_1 \geqq E_2 + E_3 + E_4$. However, if $E_1 < E_2 + E_3 + E_4$ then E_1 should be further compared to $E_2 + E_3$ only following this exact procedure to refine its value <, =, or > the sum of $E_2 + E_3$. This step is repeated until a value $\geqq E_2$ is determined. The same procedure is followed comparing E_2 with $E_3 + E_4$. Readjustments in values should be followed accordingly.

For example, the ranking might follow this action: A, most preferred, B, next in importance, C, next, and D last. A might be valued 10; B, 7; C, 5; and D, 2; tentatively. Upon comparison, A is not equal to or preferred over B + C + D, therefore, not only does the combined weight of B, C, and D exceed A, but A must be compared to B + C. Here we decide A = B + C. If A = 10, then B + C = 10. Therefore, the values for B and C are adjusted from 7 and 5 to 6 and 4 respectively. B is evaluated next by comparing with C + D. If B (6) is decided to be more important than C (4) + D (2), then the value of D is changed to 1. This makes B (6) greater than C + D (5) and does not disturb the previous relationship of A (10) = B (6) + C (4) and A (10) < B (16) + C (4) + D (1).

EVALUATION	CRITERIA (A,B,C, OR D)	TENTATIVE VALUE ASSIGNED	FINAL VALUE ASSIGNED
E_1			
E_2			
E_3			
E_4			

DATA SURVEY SHEET

1.

I. Evaluation (E) — Method (M)

	I	II	III	IV
	(P_{1j})	(P_{2j})	(P_{3j})	(P_{4j})
A	5	7	10	8
B	1	4	8	10
C	2	5	8	10
D	4	6	9	10

II. Evaluation	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	D	7
E_3	B	3
E_4	A	2

$$\Sigma P_{ij}(M_I) = P_{i1}E_1 + P_{i2}E_2 + \cdots P_{in}E_n$$

$$= P_{11}E_1 + P_{12}E_2 + P_{13}E_3 + P_{14}E_4$$

$$= (2)(10) + (4)(7) + (1)(3) + (5)(2)$$

$$= 20 + 28 + 3 + 10$$

$$= 61 = 10.5\%$$

Similarly, $\Sigma P_{ij}(M_{II}) = 118 = 20.3\%$

$\Sigma P_{ij}(M_{III}) = 187 = 32.1\%$

$\Sigma P_{ij}(M_{IV}) = 216 = 37.1\%$

DATA SURVEY SHEET

2.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	7	8	10	9
B	7	9	10	8
C	4	5	10	10
D	5	6	9	10

II.

Evaluation	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	D	8
E_3	B	6
E_4	A	3

$$\Sigma P_{ij}(M_I) = 143 = 17.1\%$$

$$\Sigma P_{ij}(M_{II}) = 176 = 21.0\%$$

$$\Sigma P_{ij}(M_{III}) = 262 = 31.3\%$$

$$\Sigma P_{ij}(M_{IV}) = 255 = 30.5\%$$

DATA SURVEY SHEET

3.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	2	5	7	10
B	4	5	8	10
C	2	4	8	10
D	7	8	9	10

II. Evaluation

Evaluation	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	A	5
E_3	D	2
E_4	B	1

$\Sigma P_{ij}(M_I) = 48 = 8.6\%$

$\Sigma P_{ij}(M_{II}) = 86 = 15.5\%$

$\Sigma P_{ij}(M_{III}) = 141 = 25.4\%$

$\Sigma P_{ij}(M_{IV}) = 280 = 50.4\%$

DATA SURVEY SHEET

4.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	10	10	10	10
B	10	10	10	10
C	2	7	5	10
D	2	7	5	10

II. Evaluation	Criteria Preference	Final Value Assigned
E_1	D	10
E_2	C	3
E_3	B	2
E_4	A	1

$$\Sigma P_{ij}(M_I) = 56 = 12.9\%$$

$$\Sigma P_{ij}(M_{II}) = 121 = 27.9\%$$

$$\Sigma P_{ij}(M_{III}) = 95 = 22.0\%$$

$$\Sigma P_{ij}(M_{IV}) = 160 = 37.0\%$$

DATA SURVEY SHEET

5.

I. Evaluation (E)	Method (M) I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	5	7	9	10
B	5	6	9	10
C	4	8	9	10
D	3	7	9	10

II. Evaluation	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	D	6
E_3	A	2
E_4	B	2

$\Sigma P_{ij}(M_I) = 78 = 12.9\%$

$\Sigma P_{ij}(M_{II}) = 148 = 24.4\%$

$\Sigma P_{ij}(M_{III}) = 180 = 29.7\%$

$\Sigma P_{ij}(M_{IV}) = 200 = 33.0\%$

DATA SURVEY SHEET

6.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	1	10	8	4
B	1	5	10	8
C	1	3	10	7
D	1	3	10	7

II. Evaluation

Evaluation	Criteria Preference	Final Value Assigned
E_1	A	10
E_2	D	8
E_3	C	6
E_4	B	1

$$\Sigma P_{ij}(M_I) = 25 = 4.6\%$$

$$\Sigma P_{ij}(M_{II}) = 147 = 26.8\%$$

$$\Sigma P_{ij}(M_{III}) = 230 = 42.0\%$$

$$\Sigma P_{ij}(M_{IV}) = 146 = 26.6\%$$

DATA SURVEY SHEET

7.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	0	5	10	5
B	0	5	10	10
C	0	5	8	10
D	0	5	8	10

II. Evaluation

Evaluation	Criteria Preference	Final Value Assigned
E_1	D	10
E_2	C	8
E_3	A	2
E_4	B	1

$$\Sigma P_{ij}(M_I) = 0 = 0\%$$

$$\Sigma P_{ij}(M_{II}) = 105 = 21.9\%$$

$$\Sigma P_{ij}(M_{III}) = 174 = 36.3\%$$

$$\Sigma P_{ij}(M_{IV}) = 200 = 41.7\%$$

DATA SURVEY SHEET

8.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	5	7	10	9
B	2	6	10	8
C	3	3	10	6
D	4	4	10	8

II. Evaluation

	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	D	7
E_3	B	2
E_4	A	1

$$\Sigma P_{ij}(M_{I}) = 67 = 14.0\%$$
$$\Sigma P_{ij}(M_{II}) = 77 = 16.1\%$$
$$\Sigma P_{ij}(M_{III}) = 200 = 41.7\%$$
$$\Sigma P_{ij}(M_{IV}) = 135 = 28.2\%$$

DATA SURVEY SHEET

9.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	0	6	8	10
B	0	5	7	9
C	2	4	9	10
D	1	4	9	10

II. Evaluation

	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	D	8
E_3	B	5
E_4	A	3

$$\Sigma P_{ij}(M_I) = 28 = 4.5\%$$
$$\Sigma P_{ij}(M_{II}) = 115 = 18.6\%$$
$$\Sigma P_{ij}(M_{III}) = 221 = 35.7\%$$
$$\Sigma P_{ij}(M_{IV}) = 255 = 41.2\%$$

DATA SURVEY SHEET

10.

I. Evaluation (E) Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	10	8	6	4
B	8	6	10	4
C	4	5	7	10
D	7	8	9	10

II. Evaluation

	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	A	8
E_3	D	5
E_4	B	3

$\Sigma P_{ij}(M_I) = 179 = 24.3\%$

$\Sigma P_{ij}(M_{II}) = 172 = 23.3\%$

$\Sigma P_{ij}(M_{III}) = 193 = 26.1\%$

$\Sigma P_{ij}(M_{IV}) = 194 = 26.3\%$

DATA SURVEY SHEET

11.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	2	3	5	10
B	3	4	6	10
C	3	6	8	10
D	3	5	8	10

II. Evaluation	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	D	6
E_3	B	4
E_4	A	2

$$\Sigma P_{ij}(M_I) = 64 = 13.1\%$$
$$\Sigma P_{ij}(M_{II}) = 97 = 19.8\%$$
$$\Sigma P_{ij}(M_{III}) = 138 = 28.2\%$$
$$\Sigma P_{ij}(M_{IV}) = 190 = 38.9\%$$

DATA SURVEY SHEET

12.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	3	4	5	8
B	3	4	5	8
C	4	5	10	10
D	5	5	10	10

II. Evaluation

Evaluation	Criteria Preference	Final Value Assigned
E_1	C	10
E_2	D	10
E_3	B	5
E_4	A	5

$\Sigma P_{ij}(M_I) = 120 = 15.2\%$

$\Sigma P_{ij}(M_{II}) = 140 = 17.7\%$

$\Sigma P_{ij}(M_{III}) = 250 = 31.6\%$

$\Sigma P_{ij}(M_{IV}) = 280 = 25.4\%$

DATA SURVEY SHEET

13.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	8	10	4	3
B	4	5	8	10
C	2	6	9	10
D	4	8	10	10

II. Evaluation

Evaluation	Criteria Preference	Final Value Assigned
E_1	D	10
E_2	C	9
E_3	B	4
E_4	A	4

$$\Sigma P_{ij}(M_{I}) = 106 = 13.7\%$$
$$\Sigma P_{ij}(M_{II}) = 194 = 25.2\%$$
$$\Sigma P_{ij}(M_{III}) = 229 = 29.7\%$$
$$\Sigma P_{ij}(M_{IV}) = 242 = 31.4\%$$

DATA SURVEY SHEET

14.

I. Evaluation (E) — Method (M)

	I (P_{1j})	II (P_{2j})	III (P_{3j})	IV (P_{4j})
A	3	5	10	9
B	5	7	10	8
C	4	5	8	10
D	1	4	9	10

II. Evaluation

	Criteria Preference	Final Value Assigned
E_1	D	10
E_2	C	7
E_3	B	3
E_4	A	2

$\Sigma P_{ij}(M_I) = 59 = 10.3\%$

$\Sigma P_{ij}(M_{II}) = 106 = 18.5\%$

$\Sigma P_{ij}(M_{III}) = 196 = 34.2\%$

$\Sigma P_{ij}(M_{IV}) = 212 = 37.0\%$

APPENDIX E

SAMPLE CALCULATIONS

SAMPLE CALCULATIONS FOR BARTLETT'S TEST OF EQUAL VARIANCES

Sample Size = n_i = 14

$\Sigma n_i = N = 56$

Number of samples = K = 4

s_i = unbiased estimate of the standard deviation

$s_I = 5.99$

$s_{II} = 3.87$

$s_{III} = 5.78$

$s_{IV} = 6.66$

Bartlett's Test is shown by:

$$F = \frac{f_2 M}{f_1 (b-M)}$$

$$M = (N-K) \ln s_p^2 - \Sigma \left[(n_i-1) \ln s_i^2 \right]$$

where s_i^2 = the variance of the i^{th} sample; the pooled variance

$$= s_p^2 = \frac{\Sigma (n_i-1) s_i^2}{N-K}$$

$$= \frac{13(35.88 + 14.98 + 33.41 + 44.35)}{56-4}$$

$$= 32.15$$

$\ln 32.15 = 3.44$

$\ln 35.88 = 3.58$

$\ln 14.98 = 2.71$

$\ln 33.41 = 3.51$

$\ln 44.35 = 3.79$

$\Sigma \ln s_i^2 = 13.59$

$$M = 52(3.44) - 13(13.59)$$

$$= 2.17$$

$$A = \frac{1}{3(K-1)}\left[\Sigma\left(\frac{1}{n_i-1}\right) - \frac{1}{N-K}\right]$$

$$= \frac{1}{(3)(3)}\left[\frac{4}{13} - \frac{1}{52}\right] = 0.0321$$

$$f_1 = K-1 = 3$$

$$f_2 = \frac{K+1}{A^2}$$

$$= \frac{5}{(0.032)^2} = 4868.5$$

$$b = \frac{f_2}{1 - A + \left(\frac{2}{f_2}\right)}$$

$$= \frac{4868.5}{1 - 0.0321 + \left(\frac{2}{4868.5}\right)} = 5027.9$$

$$F = \frac{f_2 M}{f_1(b-M)}$$

$$= \frac{(4868.5)(2.17)}{(3)(5027.9 - 2.17)} = 0.701$$

At 5% level of significance, $F_{(3,\ 4868.5)} = 2.60$

SAMPLE CALCULATIONS FOR STUDENT'S t DISTRIBUTION

	Method			
	I	II	III	IV
$\bar{X}$	11.55	21.21	31.86	35.34
s	5.99	3.87	5.78	6.66

$$s_p^2 = \frac{\Sigma(n_i-1)\ s_i^2}{N-K}$$

$$\text{Student's}\quad t = \frac{\bar{X}_1 - \bar{X}_2}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$n_i = 14;\quad N = 28;\quad K = 2;$

Degrees of freedom (d.f.) $= n_1 + n_2 - 2 = 26$

For methods III and IV:

$$s_p = \sqrt{\frac{13\left[(5.78)^2 + (6.66)^2\right]}{26}} = 6.24$$

$$t = \frac{35.34 - 31.86}{6.24\sqrt{\frac{1}{14} + \frac{1}{14}}} = 1.48$$

At d.f. = 26, $t_{.95} = 1.71$

For methods I and II,

$$s_p = \sqrt{\frac{13\left[(5.99)^2 + (3.87)^2\right]}{26}} = 5.11$$

$$t = \frac{21.21 - 11.55}{5.11 \sqrt{\frac{1}{14} + \frac{1}{14}}} = 5.07$$

At d.f. = 26, $t_{.95} = 1.71$

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